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LONG-RANGE ARTILLERY SOUND RANGING: 'PASS' 6R-8 SOUND RANGING D--ETC(U)  
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# **LONG-RANGE ARTILLERY SOUND RANGING: "PASS" GR-8 SOUND RANGING DATA**

**MARCH 1979**

**By**

**ABEL J. BLANCO**

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US Army Electronics Research and Development Command

**Atmospheric Sciences Laboratory**

White Sands Missile Range, NM 88002

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20. ABSTRACT (cont)

meteorological correction and these automatic aids, this analysis suggests a significant improvement over the manual process of selecting the arrival times. With these aids the record reader was able to provide more timely arrival time data that permitted sound source location with miss-distances less than 1.5 percent of the over 10 km range targets.

## SUMMARY

The first step for rereading all the GR-8 record tapes was to use the manually selected arrival times to derive the direction rays and automatically plot their intersections. Using this as an aid the record reader could identify which microphone record needed verification. In the case of unknown target location, this type of editing was limited to checking only the rays that deviated significantly from the well-defined intersection cluster. It should be pointed out that for field data a single point intersection does not necessarily provide the best estimate of source location. Using the centroid method for determining the final location, the spread of the polygon of error (defined by the ten intersections of the five rays) may be as high as an equivalent 400-m radius.

Another aid was added to the automatic plot, which required an initial estimate of the sound source direction. If an accurate initial guess of the direction of the sound source were not available, the problem could be solved by using the manual method, and the computed direction of the source location would then be used. The available meteorological message was also used in computing the theoretical arrival time. The second time the record reader examined the GR-8 tape, the computed arrival time for each microphone was displayed. The reader looked at that particular point and then adjusted to keep the same selection criteria (break, valley, crossover, or peak) for all six microphone traces. The appendix contains the selected arrival times, and the plots of the direction rays confirm the spread for each fix contained in the research data base.

With the use of newer techniques, including editing procedures to more accurately select arrival times and use of accurate meteorological data, longer range sound ranging targets were located within 1.5 percent of the target range.

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## INTRODUCTION

State of the art has enhanced the artillery capability so that today tactical artillery support is effectively provided at much longer ranges. In response to this new capability, a current target acquisition approach is reexamined with the emphasis on locating enemy artillery targets at ranges greater than 10 km. Since World War I, artillery sound ranging has yielded more confirmed target locations than all other methods combined. This method is a passive technique and requires an array of microphones that provide the artillery record reader with data identifying the sound arrival time at each microphone. It is fundamentally a direction finding technique which uses the sound arrival time data to derive direction rays. The artilleryman then uses the intersection of the different rays to estimate a sound source location.

Between October and December 1974, a ground recorder (GR-8) sound ranging set with six microphones was operated during the Atmospheric Sciences Laboratory meteorological comparisons test (Project PASS).<sup>1</sup> During this experiment the sound wave from explosions at surveyed locations were monitored by using a surveyed linear-array of hot-wire-type microphones (T-23). A basic review of the manual record reading procedure is included in the report for providing general information. The data base for the GR-8 sound arrival times is also included in the report. Some results concerning the interactions between the best available meteorological conditions,<sup>2</sup> the microphone record readings, and the centroid method employed for determining the sound source locations are presented.

Automated assistance in record reading is emphasized, with a significant improvement demonstrated on the solution of the long-range artillery sound ranging problem. Data collected during the experiment and read immediately thereafter were used to compute the sound source location. These results were then compared to those derived by employing automated aides in record reading of sound arrival times.

## EXPERIMENTAL APPROACH

To demonstrate the accuracy of sound ranging at ranges greater than 10 km, a comprehensive experiment was performed to acquire the required sound ranging data. Data from surveyed microphones were used to calculate the position of the surveyed sound sources.

<sup>1</sup>K. M. Barnett, 1976, "A Description of the Artillery Meteorological Comparisons at White Sands Missile Range, October 1974-December 1974 ("PASS" - Prototype Artillery [Meteorological] Subsystem)," ECOM-5589, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

<sup>2</sup>A. J. Blanco, 1978, "Long-Range Artillery Sound Ranging: "PASS" Meteorological Application," ASL-TR-0014, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

The GR-8 Sound Ranging System<sup>3</sup> as used on this test consisted of six (T-23) "hot wire" microphones in a four-second linear array. The remote timer unit (PE 244) and recorder (BC 1337) were powered by a 12-volt storage battery. This battery was constantly charged by a dc power source operating on normal 110-volt power. The microphones responded to atmospheric pressure changes created by 5-pound C4 explosive charges, 8-inch howitzer gun blasts, and shell bursts. Figure 1 illustrates the relative position of the sound sources with respect to the linear array of microphones, and table 1 lists the surveyed locations.

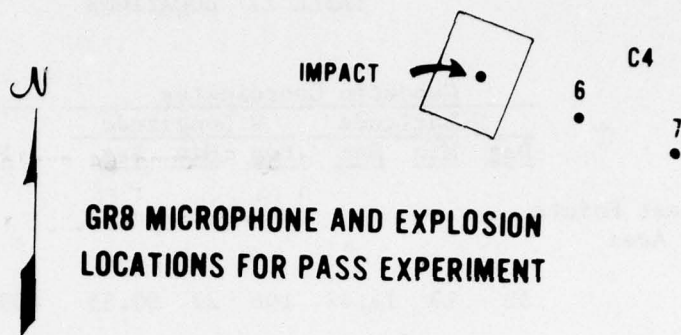
The selection of the arrival time for these air pressure changes at each microphone is used to determine the surveyed location of the source of these pressure changes. A considerable effort was made to immediately analyze the strip chart records. The time of arrival of the sound waves at each microphone was selected and entered on coding forms for later automated computations for locating the source location. All sound ranging equipment was supplied by the Target Acquisition Branch of Counter Fire Department, US Army Field Artillery School (USAFAS) at Fort Sill, Oklahoma. School personnel supervised the installation, maintenance, operation, and original data reduction of the GR-8 equipment throughout the comparisons at White Sands Missile Range (WSMR), New Mexico.

#### RECORD READING

After the equipment is checked out for operation, the attenuators located within the GR-8 recorder must be balanced. These attenuators are numbered to correspond to the microphone output they control, and each is individually adjusted. Currently there is no doctrine for an ideal setting. Only experience gained through operation under the current local conditions can determine the ideal setting. The adjustment of the attenuators determines the difference between recording usable and non-usable records. The amplitude of the microphone signals is translated into a written record on the recording paper which contains time markings as series of dots (1/10 second and 1/100 second markers) along one edge of the paper. The record can be read to 10 milliseconds and interpolated to 1 millisecond. According to Field Manual FM 6-122, the errors inherent in visual interpolation will yield arrival times accurate to within 0.003 second.<sup>4</sup>

<sup>3</sup>TM 11-2568, 1945, "Sound Ranging Set GR-8," War Department Technical Manual, Headquarters, Department of the Army, Washington, D.C.

<sup>4</sup>FM 6-122, 1964, "Artillery Sound Ranging and Flash Ranging," Department of the Army Field Manual, Headquarters, Department of the Army, Washington, D.C.



# GR8 MICROPHONE AND EXPLOSION LOCATIONS FOR PASS EXPERIMENT

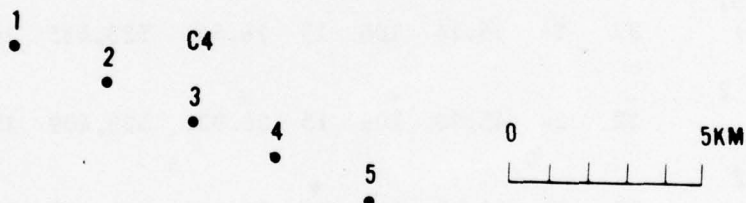
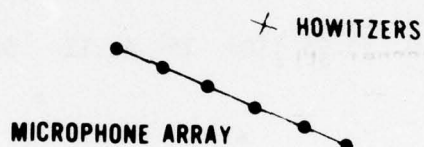


Figure 1. The relative position of the sound sources with respect to the linear array of microphones.

TABLE 1. LOCATIONS

	Geodetic Coordinates						WSM Coordinates		
	N Latitude			W Longitude			X	Y	Z
	<u>Deg</u>	<u>Min</u>	<u>Sec</u>	<u>Deg</u>	<u>Min</u>	<u>Sec</u>	<u>Ft</u>	<u>Ft</u>	<u>Ft</u>
C4 Blast Points									
South Area									
1	32	19	11.42	106	22	00.55	489,655	155,724	4,016
2	32	18	36.90	106	20	25.66	497,798	152,235	4,004
3	32	18	02.37	106	18	50.79	505,941	148,745	4,059
4	32	17	27.83	106	17	15.94	514,083	145,258	4,072
5	32	16	53.25	106	15	41.11	522,226	141,768	4,078
C4 Blast Points									
North Area									
6	32	31	07.71	106	10	20.74	549,600	228,147	4,026
7	32	30	33.06	106	08	45.73	557,742	224,658	4,086
Howitzer 1									
(12Z480)									
(center of									
trunnion)									
32	24	45.14	106	15	26.64	523,435	189,456	4,041	
Howitzer 2									
(12HM73)									
32	24	45.26	106	15	26.93	523,409	189,468	4,041	
Center of									
Impact Area									
32	31	42.35	106	11	55.79	541,457	231,636	4,034	
T-23 microphones									
(left to right)									
1	32	24	27.83	106	17	56.54	510,584	187,700	4,040
2	32	24	10.49	106	17	09.04	514,657	185,949	4,049
3	32	23	53.30	106	16	21.56	518,730	184,214	4,046
4	32	23	35.97	106	15	34.10	522,800	182,465	4,046
5	32	23	18.70	106	14	46.67	526,868	180,723	4,044
6	32	23	01.42	106	13	59.21	530,940	178,980	4,061

The point at which the trace first departs from its straight line path (or zero line) is the initial break. The low and high points on the periodic trace are called valleys and peaks, respectively. A curve representing the variation of pressure with time at a given point on a path of the sound wave is shown in figure 2. The total elapsed time from the initial break through one cycle of oscillation is the period of the sound wave.

During this field experiment a four-second displacement between adjacent microphones was selected to sound range on source targets at ranges greater than 10 km. This experiment did not duplicate collection of sound ranging data but enhanced the Army sound ranging data base to contain longer ranges at various flank angles. The linear microphone array was selected to establish an expected pattern of the arrival of the sound wave at the various microphones of the sound ranging base. For example, the C4 explosion on location 1 gave the typical pattern illustrated on figure 3. The microphones are labeled from right to left as one faces the direction of observation for sound ranging. The current doctrine is to sound range in a forward zone coverage defined within a  $\pm 50$ -degree angle from the perpendicular bisector of the microphone linear array.

The selection criteria were constrained to using the same signature point on all microphone traces within a given pattern for the triangulation of the sound source. There are four acceptable reading points: first choice, the initial break; second choice, the point at which the zero line is first crossed; third choice, at the center of the first valley; and fourth choice, at the center of the first peak.

In this controlled experiment, situations leading to contaminated records were eliminated. The microphone traces do not contain ballistic waves or signature from multiple targets or friendly fire. However, data from Project PASS contain multiple arrivals of the same sound wave at a microphone position, thereby making it difficult to select the same signature point from all microphone traces. The sound arrival times at each microphone are manually selected and provided as input to the computing device. Meteorological parameters are measured and a sound ranging met message<sup>2</sup> is calculated for input with the end result being the computation of a sound source estimate.

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<sup>2</sup>A. J. Blanco, 1978, "Long-Range Artillery Sound Ranging: "PASS" Meteorological Application," ASL-TR-0014, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

# IMPULSE WAVE OF AN 8 INCH HOWITZER

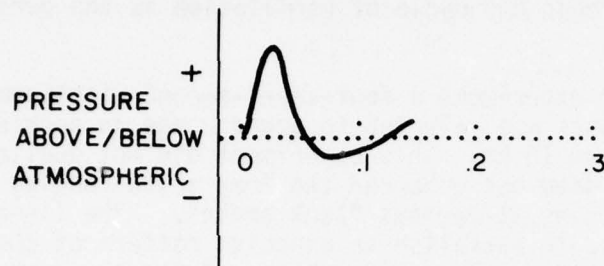


Figure 2. Impulse wave of an 8-inch howitzer has an approximate frequency of 8 cycles per second or 0.125-second period.

## EXPECTED PATTERN OF ARRIVAL TIME OF A SOUND WAVE

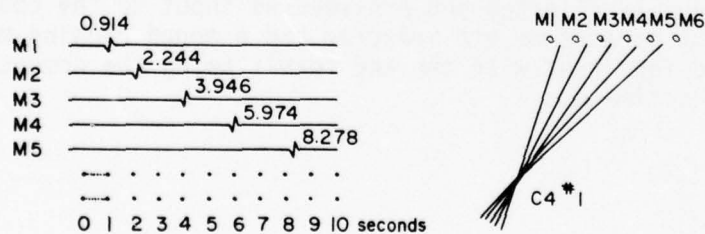


Figure 3. Expected pattern on a straight base record for C4 explosive charge at location 1.

## SOUND RANGING METHOD

The sound ranging method utilized is a simple geometric<sup>5</sup> model. This method depends on the relative arrival times at a pair of microphones. If it is assumed that the gun and all microphones are in the same plane, then the time difference between two adjacent microphones multiplied by the velocity of sound in the air equals the difference in distance traveled by the sound wave. Since by definition a hyperbola is the locus of points the difference of whose distance from two fixed points is constant, the sound source lies on a hyperbola whose foci are at the two adjacent microphones. Associated with each hyperbola is its asymptote which is a straight line passing through the midpoint between the foci and tangent to the hyperbola at infinity. Figure 4 shows the geometric construction that follows to calculate the direction of the sound source. The ten intersections of five direction rays are then used to determine the sound source. The figure also shows that the points of intersection for the asymptotes and the hyperbolas are not the same; therefore, a "curvature" correction is required when this geometric method is used for sound ranging.

## EXPERIMENTAL DATA EDITING

The first set of fixes was calculated from the microphone record reading performed immediately after the experimental event and from meteorological messages manually calculated at the time of the experiment. The fixes containing large location errors were flagged and the corresponding microphone traces were reread. A second set of fixes was then computed using the new arrival times with edited met messages. This is the original data base for the field comparison performed at WSMR in 1974. Preliminary analysis indicated that there were large errors associated with PASS artillery sound ranging. Thus the original data base was suspected of being in error, and manual plots of the direction rays revealed a need for rereading all the original microphone records.

The automatic plotting indicated numerous cases where one direction ray was almost parallel to another. Since the intersection points will be widely distributed, the final estimate will contain a large miss. There were cases when the large polygon (2000 m) defined by the intersection of the direction rays yielded a good location but only after the centroid procedure was performed to obtain the fix. Quality research cannot be based on this type of information; therefore, a complete new reading of the microphone traces was necessary. The original meteorological data was edited for errors and a new calculation of the FM 6-15 sound ranging

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<sup>5</sup>R. P. Lee, 1969, "A Dimensional Analysis of the Errors of Atmospheric Sound Ranging," ECOM-5236, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

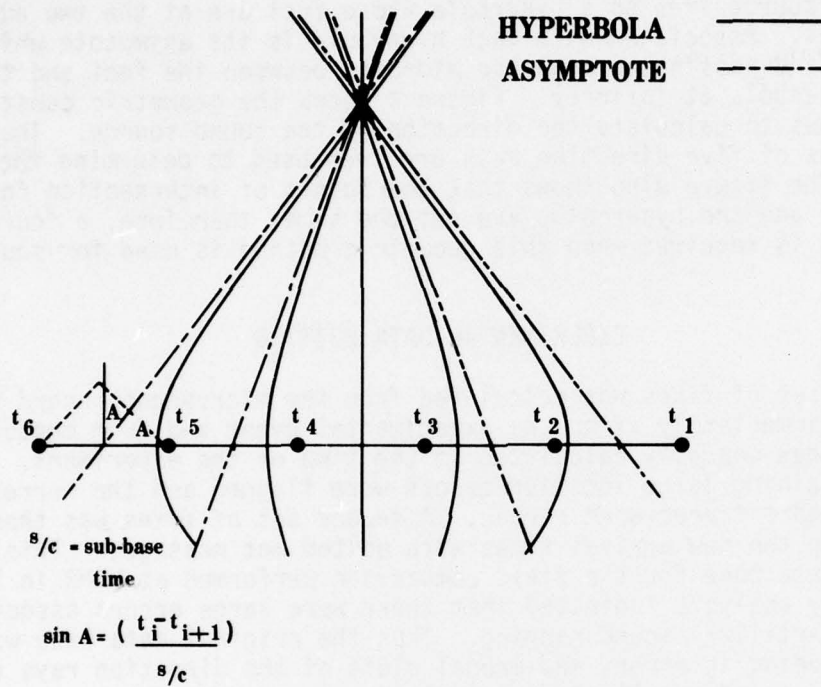


Figure 4. Fixing on a sound source by using arrival time data from a linear array of six microphones.

met messages was completed.<sup>6</sup> With the automated plot available, the record reader reread the particular microphone responsible for producing wrong direction rays. This editing was performed only in cases where the particular ray was significantly separated from the cluster of the other intersections. The editing procedure automatically plots the five direction rays derived from the adjacent microphones of the regular linear array. The same procedure is currently manually performed in field application. The selected arrival times are suspected of being in error when they deviate from the assumed pattern of arrival times. The artilleryman, plotting the direction rays, identifies particular microphones that need verification of arrival time reading.

The automated processes available for the reading of the original records included the plotting of the direction rays (EDIT 1) and an aid in selecting the particular arrival time produced by a single wave passing through all six microphones (EDIT 2). Figure 5 illustrates the type of problem the record reader encounters when he needs to select from multipath arrivals. A single signature point from the common wave needs to be selected from all six microphones. The triangulation represents the fix on location 3. The first intersection represents the polygon of error defined by the "immediately read arrival times." A fix with a radial miss of about 100 m was computed. The next intersection is one derived by using manual editing from the automated plotting. Finally, the last intersection is obtained from using the automated aid of selecting the arrival times from a single pressure wave passing through all six microphones. A survey of the original microphone traces (bottom of figure 5) reveals the quality of the available data. Note that the polarity is not the same for all microphones; however, EDIT 2 aids the record reader in selecting the appropriate arrival times considering the initial polarity connection between the microphones and recorder.

The formulation for the EDIT 2 process was developed using the current method of sound ranging. The procedure is expressed in the following functional form:

relative difference of  $t_i$ 's + temperature correction + wind correction  
yields direction

$$(t_i - t_{i+1}) + (t_i - t_{i+1}) \left( \sqrt{\frac{T_e}{T_{std}}} - 1 \right) + \frac{W}{V^2} S \cos \theta = \frac{S}{C} \sin A$$

<sup>6</sup>E. M. D'Arcy, 1977, "PASS 500 mb Rawinsonde Data," Vol 1 and 2, ECOM-DR-74-4, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

# EDITING AID AUTOMATED

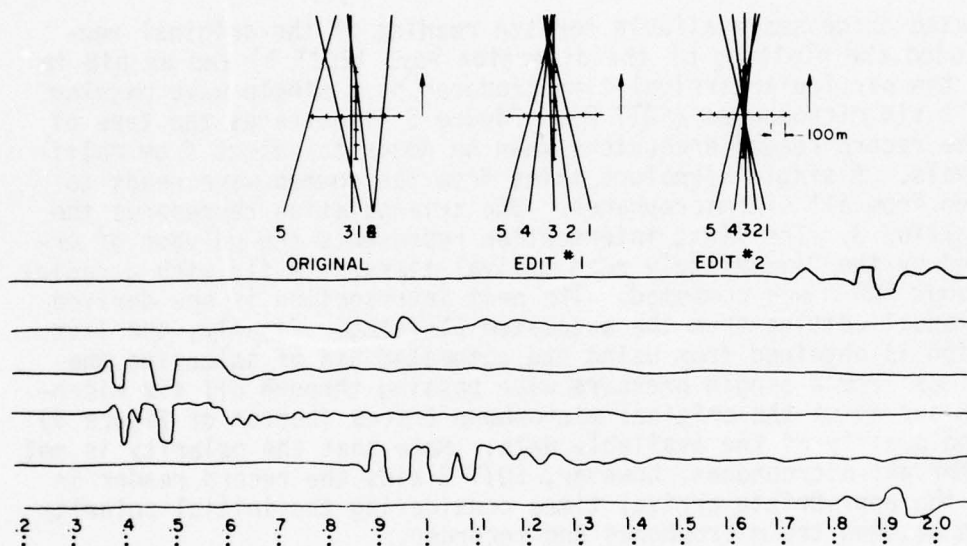


Figure 5. Automated aids available for selecting the arrival times from a single pressure wave passing through all six microphones.

$$(t_i - t_{i+1}) \sqrt{\frac{T_e}{T_{std}}} + \frac{W}{V^2} S \cos \theta = \frac{S}{C} \sin A$$

$$t_i - t_{i+1} = \left( \frac{S}{C} \sin A - \frac{W}{V^2} S \cos \theta \right) \sqrt{\frac{T_{std}}{T_e}}$$

$$t_i = t_{i+1} + \left( \frac{S}{C} \sin A - \frac{W}{V^2} S \cos \theta \right) \sqrt{\frac{T_{std}}{T_e}}$$

where

$t_i$  = arrival time at microphone (sec)

$T_e$  = effective temperature ( $^{\circ}$ K)

$T_{std}$  = 283.16 $^{\circ}$ K

$W$  = effective wind speed (m/sec)

$\theta$  = angle of the effective wind direction with respect to linear array of microphones (deg)

$S$  = distance between adjacent microphones (m)

$V$  = speed of sound at given temperature (m/sec)

$C$  = speed of sound at std temperature (m/sec)

$A$  = direction of sound with respect to perpendicular bisector of  $S$

For the operation of this editing routine, the record reader picks the best defined signal from the six microphone traces on the GR-8 record. This signal, together with the microphone positions, meteorological message, and direction of the sound source, is required input to the EDIT 2 process which will provide a display of the six computed arrival times. The reader proceeds to locate the suggested point on each microphone trace then adjusts to select the arrival times that correspond to the selection criteria (break, valley, crossover, or peak) of the trace that initiated the EDIT 2 process. The research data base for the selected arrival times is contained in the appendix. The plots of the direction rays for each fix are also included to express their corresponding polygon of error.

## EXPERIMENTAL RESULTS

The original microphone traces are categorized into usable and unusable sets of data. The unusable set contained those events wherein more than two microphone traces were unreadable. More events could have been usable had proper microphone attenuation adjustment been maintained. The unusable cases are not included in this data base and the planned sample size was reduced to the ranges listed in table 2; e.g., at the bottom of column 1 the entry 74/35 indicates the total events to be 74 and the usable data to be 35. In all, more than 1/2 of the experimental data was usable.

One of the high quality traces was used to postulate the accuracy of record reading. As a sample, seven record readers (professional scientists) were provided with a particular strip chart containing information obtained from six microphone traces. The readers were instructed to read the arrival time at the "break points" of the sound signature. The results indicated a sigma range of 3 to 9 milliseconds. The most accurate reading corresponded to a microphone trace with a well-defined signature, while the largest sigma (9 milliseconds) involved a microphone trace that contained interference. As discussed in the Record Reading section, this interference can be attenuated and well-defined balanced data can be provided to the record reader.

The original results derived from using the centroid method of sound ranging are listed in table 3. Comparing the miss-location distribution with table 4 indicates the improvement afforded by the use of automated assistance in record reading. The results of interest are the computed miss-distance from the actual source location. Figure 6 contains a set of 54 fixes on a surveyed target at 11.5 km and 13 degrees flank angle. The elliptical one probable error is used to illustrate the met interaction since the arrival times from the research data base are considered the actual arrivals. The axis center indicates the location of surveyed target 2, and the radial distance from the center to any point is the sound ranging miss-distance in fixing on the target. This scatter yields a distribution about a mean distance of 5 m in the cross and 54 m in the range. Overall the results are encouraging because this probable error is within the accepted 1.5 percent of target range accuracy.

## CONCLUSIONS

The research arrival time data base is available, and the effect of proposed sound ranging meteorological messages can be evaluated. The position and size of the ellipse in figure 6 can be used as an indicator for selecting the actual effective met the sound experienced as it traveled from its origin to each microphone. The time and space variability between the measured met parameters and the path of propagation should also be considered in selecting the best meteorological correction technique.

TABLE 2. C4 EXPLOSIVE CHARGES CATEGORIZED AS TO TOTAL EVENTS/USABLE DATA.

Date (1974)	Locations						
	1	2	3	4	5	6	7
1 Nov	3/1	5/5	4/2	5/2	3/0	0/0	0/0
2 Nov	7/3	9/9	7/7	6/5	7/0	0/0	0/0
4 Nov	7/1	9/2	7/1	6/1	7/0	0/0	0/0
6 Nov	3/2	5/5	4/3	4/4	4/4	0/0	0/0
7 Nov	8/3	8/2	7/4	6/6	7/6	0/0	0/0
8 Nov	2/1	5/5	4/3	4/4	4/3	0/0	0/0
11 Nov	3/1	5/1	4/0	4/0	3/0	0/0	0/0
12 Nov	3/3	5/3	4/2	4/3	4/3	0/0	0/0
14 Nov	8/4	8/0	7/3	6/4	7/6	0/0	0/0
15 Nov	6/4	7/5	8/6	6/6	5/3	0/0	0/0
18 Nov	3/1	5/4	4/4	4/4	4/1	0/0	0/0
19 Nov	2/0	3/2	2/2	2/2	1/0	2/0	9/3
20 Nov	1/0	3/1	3/0	2/1	1/0	5/2	4/0
23 Nov	3/0	4/1	4/1	4/1	2/1	9/6	9/0
26 Nov	2/1	3/1	2/0	2/0	1/0	5/4	5/3
27 Nov	2/1	3/3	2/2	2/2	1/0	5/0	5/0
2 Dec	3/2	5/4	4/3	4/3	3/1	9/6	9/5
3 Dec	2/1	3/3	2/2	2/2	1/0	7/1	5/1
5 Dec	3/3	3/2	3/2	4/4	2/0	13/0	1/0
7 Dec	3/3	6/6	6/4	5/3	2/1	11/3	11/3
	74/35	104/64	88/51	82/57	69/29	66/22	58/15

TABLE 3. CUMULATIVE FREQUENCY OF LOCATION MISSES FROM  
ORIGINAL ANALYSIS USING THE CENTROID METHOD  
OF SOUND RANGING

Target No.	1	2	3	4	5	6	7
Range (km)	11.5	11.5	11.5	11.5	11.5	16.0	16.0
Flank (deg)	25	13	0	-13	-25	-9	-23

<u>Radial Miss (m)</u>							
25	0	1	2	1	0	0	0
50	0	3	2	3	0	2	0
75	1	6	8	5	0	4	0
100	1	6	12	10	1	5	0
150	2	10	19	15	6	11	0
200	5	17	21	16	6	12	0
300	9	23	32	24	9	13	4
400	11	30	37	26	14	14	6
500	11	35	38	28	18	16	7
600	12	39	40	31	20	17	9
700	13	41	41	33	21	19	9
800	14	42	43	33	23	19	9
900	18	44	44	36	24	20	10
>1000	39	59	51	44	38	34	25

TABLE 4. CUMULATIVE FREQUENCY OF LOCATION MISSES FROM  
AUTOMATED ASSIST ANALYSIS USING THE CENTROID  
METHOD OF SOUND RANGING.

Target No.	1	2	3	4	5	6	7
Range (km)	11.5	11.5	11.5	11.5	11.5	16.0	16.0
Flank (deg)	25	13	0	-13	-25	-9	-23

<u>Radial Miss (m)</u>							
25	1	2	3	4	0	0	0
50	4	14	8	9	3	1	1
75	8	19	17	19	4	6	1
100	11	27	25	23	12	8	4
150	18	40	35	33	16	10	5
200	23	48	38	40	19	11	6
300	24	54	43	44	22	15	8
400	25	54	43	44	24	15	10
>400	39	59	51	44	38	34	25

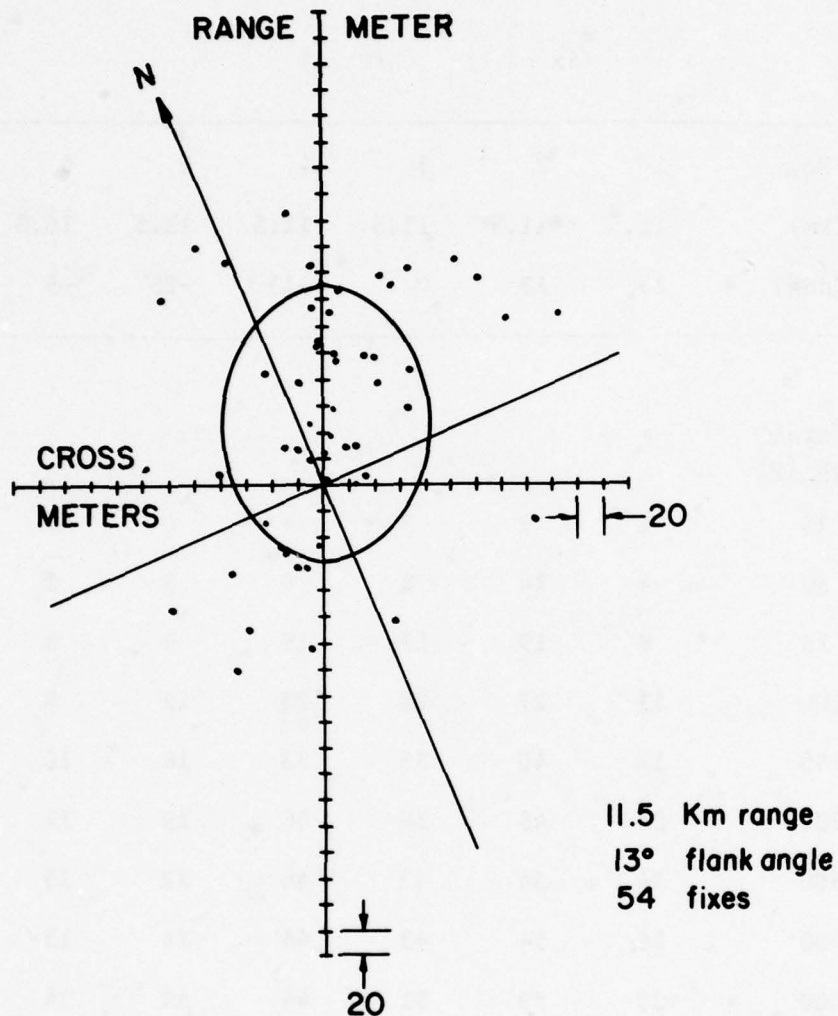


Figure 6. Illustrates the 54 fixes for source location 2 with the one probable error ellipse. The sound ranging method employed is the geometric with the centroid solution of direction ray intersection.

In comparing proposed solution algorithms, one must consider that the nature of some algorithms contains editing procedures, for example, the centroid versus the median solution. Using this data base the improvement of the median solution will be limited because the arrival times have already been adjusted to their most representative value. Therefore, the median solution will fix on the center of the ray intersection distribution which has already been edited.

A final comment that this analysis suggests is that expert supervision of adjusting microphone attenuation and reading microphone records should be maintained. If this procedure is followed, more long-range targets may be located by the sound ranging method.

#### REFERENCES

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2. Blanco, Abel J., 1978, "Long-Range Artillery Sound Ranging: "PASS" Meteorological Application," ASL-TR-0014, Atmospheric Sciences Laboratory, White Sands Missile Range, NM.
3. TM 11-2568, 1945, "Sound Ranging Set GR-8," War Department Technical Manual, Headquarters, Department of the Army, Washington, D.C.
4. FM 6-122, 1964, "Artillery Sound Ranging and Flash Ranging," Department of the Army Field Manual, Headquarters, Department of the Army, Washington, D.C.
5. Lee, Robert P., 1969, "A Dimensional Analysis of the Errors of Atmospheric Sound Ranging," ECOM-5236, Atmospheric Sciences Laboratory, White Sands Missile Range, NM.
6. D'Arcy, Edward M., 1977, "PASS 500 mb Rawinsonde Data," Vol 1 and 2, ECOM-DR-74-4, Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

## APPENDIX

### SOUND RANGING ARRIVAL TIME DATA FROM THE GR-8 DATA RECORDS COLLECTED DURING "PASS"

Table A1 identifies the fix with the date and time of day.

The data base is listed in the following format: fix number, selected arrival time for microphones 1 through 6, and met data used to make corrections on fix.<sup>2</sup> The data base is listed normalized to the earliest arrival time indicating the effect of met during the same day. Finally a plot of the direction rays is included for each of the listed cases. The wind direction and relative wind speed are also illustrated to the right of each polygon of error. The order of plots is from left to right, and the scale is 100 m per grid.

<sup>2</sup>A. J. Blanco, 1978, "Long-Range Artillery Sound Ranging: "PASS" Meteorological Application," ASL-TR-0014, Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

TABLE A1. TIME OF DAY FOR EACH FIX IN DATA BASE

Date (1974)	Source Location						
	1	2	3	4	5	6	7
1 Nov	1 614 --- ---	1 414 2 514 3 626 4 712	1 655 2 738 ---	1 714 2 755 ---	---	---	---
2 Nov	---	5 501 6 540 7 656 8 741 9 818 10 855 11 1058	3 559 4 727 5 807 6 908 7 1013 8 1155	3 458 4 724 5 900 6 955 7 1120	---	---	---
4 Nov	5 458 ---	12 443 13 511 ---	9 536 ---	8 955 ---	---	---	---
6 Nov	6 723 7 746 ---	14 658 15 819 16 845 17 931	10 741 11 833 12 927	9 649 10 721 ---	1 700 2 757 3 835 4 951	---	---
7 Nov	8 622 9 720 10 825 ---	18 632 19 737 ---	13 444 14 619 15 722 16 846 ---	11 354 12 425 13 829 14 1045	5 411 6 540 7 634 8 740 9 844 10 1033	---	---
8 Nov	---	20 1257 21 1340 22 1448 23 1535	17 1247 18 1520 19 1642 ---	15 1336 16 1452 17 1538 ---	11 1425 12 1523 13 1731 ---	---	---
11 Nov	12 530 ---	24 646 ---	---	---	---	---	---
12 Nov	13 556 14 757 ---	---	20 421 21 759 ---	---	---	---	---
14 Nov	15 425 16 524 17 721 ---	---	22 454 23 724 24 1121 ---	18 356 19 839 20 930 21 1045 ---	14 643 15 741 16 851 17 1031 18 1136 ---	---	---
15 Nov	18 634 19 740 20 805 21 1057 ---	25 704 26 752 27 833 28 1034 29 1114 ---	25 430 26 500 27 736 28 745 29 854 30 1151 ---	22 457 23 538 ---	19 637 20 800 ---	---	---
18 Nov	22 520 ---	30 455 31 558 32 810 33 849 ---	31 419 32 601 33 751 34 808 ---	27 452 28 516 29 706 30 754 ---	21 721 ---	---	---
19 Nov	---	34 540 35 817 ---	---	31 613 32 716 ---	---	---	1 629 2 805 3 811
20 Nov	---	36 1339 ---	---	---	---	1 1535 ---	---
23 Nov	---	37 635 ---	---	33 715 ---	22 756 ---	2 805 3 1205 4 1305 5 1405 ---	---
26 Nov	---	38 1235 ---	---	---	---	6 1505 ---	4 1245 5 1325 6 1522
27 Nov	23 1215 24 1255 ---	39 935 40 1215 41 1315 ---	35 955 ---	34 1015 35 1131 ---	---	---	---
2 Dec	25 515 26 856 ---	42 535 43 817 44 916 ---	36 555 37 757 38 1004 ---	36 717 37 1022 38 1115 ---	23 657 ---	7 705 8 905 9 905 10 1007 11 1105 ---	7 545 8 625 9 825 10 1025 11 1225
3 Dec	27 545 ---	45 605 46 845 47 945 ---	39 625 40 825 ---	39 645 40 745 ---	---	12 642 ---	12 527
5 Dec	---	48 1135 ---	---	41 1315 42 1615 43 1715 ---	---	---	---
7 Dec	29 536 30 855 31 1255 ---	49 550 50 815 51 915 52 1215 53 1315 54 1515 ---	41 603 42 755 43 1355 1 ---	44 615 45 715 46 1416 ---	24 658 ---	13 705 14 805 15 905 ---	13 550 14 625 15 825

SOURCE 1  
SOUND RANGING ARRIVAL TIMES & MET

							.1°C/10m/knots
1	0.000	0.946	2.292	3.999	6.026	8.349	10128804
2	0.000	0.914	2.217	3.905	5.909	8.198	15535702
3	0.000	0.906	2.231	3.912	5.921	8.194	15535702
4	0.000	0.890	2.201	3.876	5.881	8.170	15535702
5	0.000	0.912	2.242	3.942	5.972	8.283	5463609
6	0.000	0.885	2.172	3.845	5.836	8.118	9063313
7	0.000	0.917	2.236	3.918	5.941	8.251	9063313
8	0.000	0.925	2.281	4.002	6.057	8.376	8511204
9	0.000	0.924	2.265	3.965	5.993	8.296	8005304
10	0.000	0.938	2.285	4.014	6.066	8.402	8005304
11	0.000	0.943	2.296	4.015	6.065	8.395	11131306
12	0.000	0.873	2.184	3.863	5.874	8.154	7063314
13	0.000	0.890	2.192	3.865	5.873	8.165	6821314
14	0.000	0.888	2.192	3.877	5.886	8.181	6821304
15	0.000	0.999	2.400	4.163	6.251	8.609	6025914
16	0.000	0.975	2.370	4.129	6.212	8.562	5526313
17	0.000	1.044	2.502	4.315	6.447	8.840	5526313
18	0.000	0.899	2.198	3.858	5.839	8.093	8833506
19	0.000	0.923	2.259	3.964	6.003	8.321	8235106
20	0.000	0.867	2.144	3.816	5.819	8.094	8235106
21	0.000	0.900	2.218	3.922	5.961	8.291	10037804
22	0.000	0.913	2.228	3.913	5.933	8.228	11146502
23	0.000	0.891	2.192	3.863	5.870	8.143	10258305
24	0.000	0.936	2.280	3.979	5.993	8.283	13240105
25	0.000	0.909	2.221	3.891	5.897	8.191	6863805
26	0.000	0.939	2.298	4.022	6.067	8.400	5200604
27	0.000	0.900	2.208	3.879	5.881	8.172	7405305
28	0.000	0.862	2.140	3.780	5.741	7.980	11841820
29	0.000	0.894	2.220	3.921	5.950	8.252	6763809
30	0.000	0.920	2.264	3.970	5.999	8.305	5663808
31	0.000	0.929	2.269	3.975	5.999	8.300	9843706



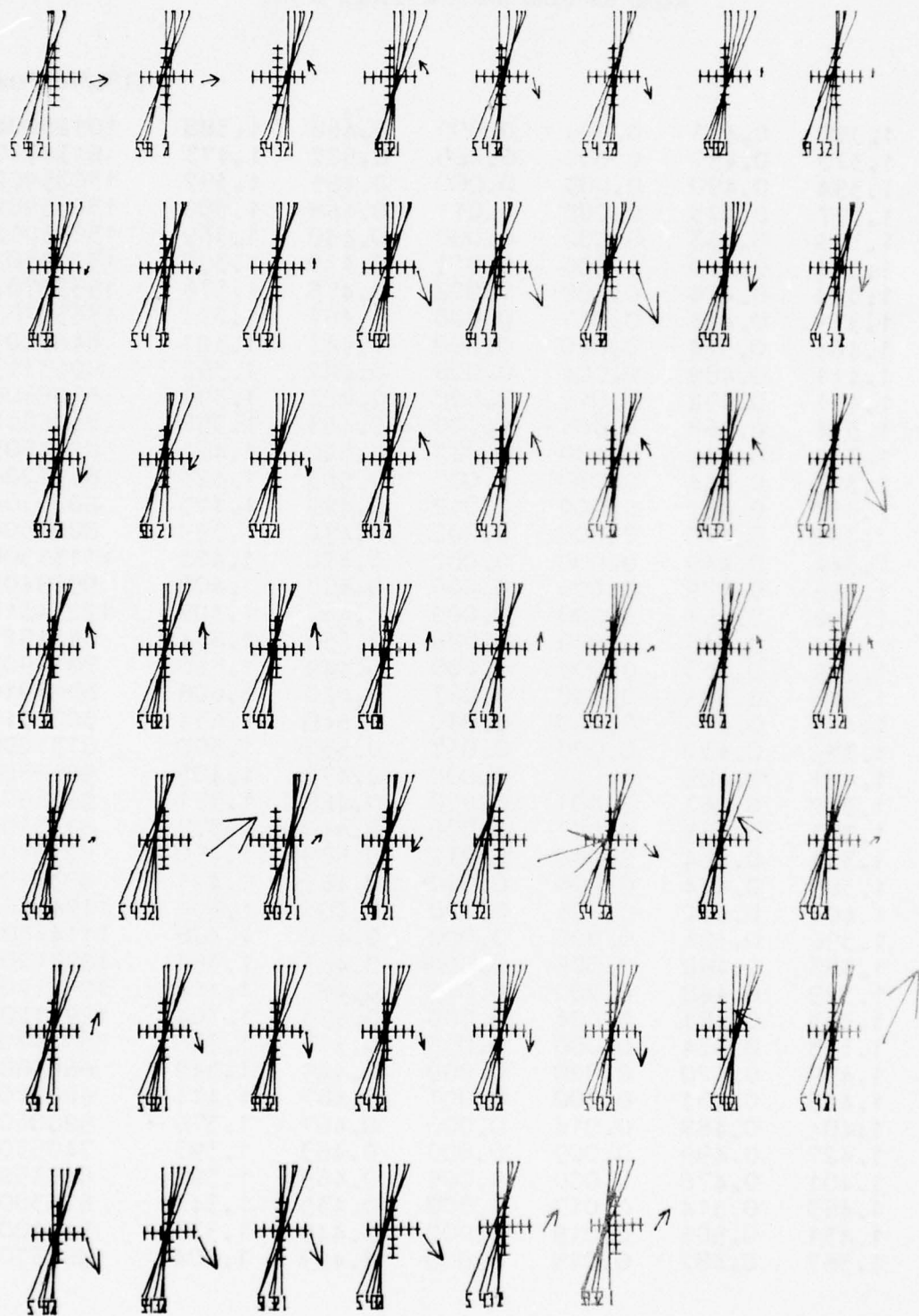
## SOURCE 2

## SOUND RANGING ARRIVAL TIMES &amp; MET

.1°C/10m/knots

1	0.000	0.001	0.477	1.413	2.746	4.462	11650905
2	0.029	0.000	0.421	1.326	2.633	4.309	11650905
3	0.032	0.000	0.434	1.323	2.642	4.332	10128804
4	0.009	0.000	0.458	1.358	2.678	4.359	10128804
5	0.000	0.000	0.447	1.333	2.642	4.332	12500505
6	0.016	0.000	0.441	1.330	2.647	4.342	12500505
7	0.000	0.000	0.462	1.366	2.676	4.352	13035902
8	0.000	0.000	0.477	1.406	2.765	4.477	13035902
9	0.000	0.016	0.486	1.397	2.728	4.420	13209302
10	0.000	0.012	0.463	1.360	2.696	4.412	13209302
11	0.001	0.000	0.472	1.381	2.706	4.410	15535702
12	0.016	0.000	0.452	1.352	2.666	4.370	5463609
13	0.001	0.000	0.454	1.371	2.720	4.432	5463609
14	0.006	0.000	0.453	1.343	2.660	4.342	9063313
15	0.004	0.000	0.460	1.378	2.715	4.424	8606606
16	0.014	0.000	0.433	1.336	2.676	4.383	8606606
17	0.018	0.000	0.441	1.351	2.684	4.376	8606606
18	0.000	0.000	0.482	1.431	2.789	4.503	8511204
19	0.000	0.002	0.469	1.389	2.729	4.439	8005304
20	0.000	0.016	0.487	1.419	2.770	4.482	11131306
21	0.000	0.002	0.455	1.366	2.704	4.409	11131306
22	0.000	0.009	0.467	1.371	2.702	4.411	9929405
23	0.008	0.000	0.477	1.403	2.752	4.469	9929405
24	0.039	0.000	0.433	1.310	2.619	4.301	10361813
25	0.000	0.025	0.506	1.435	2.791	4.529	8833506
26	0.000	0.002	0.479	1.398	2.728	4.439	8235106
27	0.000	0.030	0.510	1.443	2.790	4.520	8235106
28	0.000	0.030	0.515	1.431	2.761	4.467	10037804
29	0.012	0.000	0.466	1.366	2.688	4.395	10037804
30	0.022	0.000	0.453	1.360	2.682	4.371	11146502
31	0.000	0.007	0.467	1.390	2.721	4.414	12931203
32	0.029	0.000	0.431	1.318	2.635	4.320	12931203
33	0.000	0.002	0.462	1.360	2.680	4.373	12846602
34	0.052	0.000	0.413	1.273	2.552	4.212	12846517
35	0.094	0.000	0.386	1.237	2.502	4.137	12345503
36	0.000	0.008	0.481	1.414	2.744	4.443	16211504
37	0.068	0.000	0.398	1.241	2.509	4.150	11949820
38	0.020	0.000	0.439	1.325	2.646	4.334	10258305
39	0.000	0.047	0.577	1.547	2.938	4.686	6924808
40	0.000	0.015	0.489	1.413	2.746	4.449	11647003
41	0.020	0.000	0.447	1.363	2.674	4.352	13240105
42	0.015	0.000	0.460	1.365	2.679	4.373	6863805
43	0.003	0.000	0.464	1.376	2.710	4.408	6202706
44	0.000	0.007	0.480	1.397	2.740	4.461	5200604
45	0.000	0.000	0.458	1.370	2.700	4.407	7405305
46	0.008	0.000	0.456	1.370	2.697	4.404	6403508
47	0.007	0.000	0.460	1.369	2.692	4.401	7223708
48	0.061	0.000	0.412	1.247	2.505	4.155	11841820
49	0.000	0.001	0.452	1.357	2.671	4.371	6763809
50	0.006	0.000	0.447	1.346	2.666	4.352	5461809
51	0.025	0.000	0.455	1.352	2.681	4.364	5663808
52	0.000	0.018	0.490	1.405	2.729	4.432	7960508
53	0.000	0.003	0.449	1.355	2.678	4.391	9843706
54	0.000	0.004	0.495	1.427	2.774	4.476	9843706

# POLYGON OF ERROR PLOTS



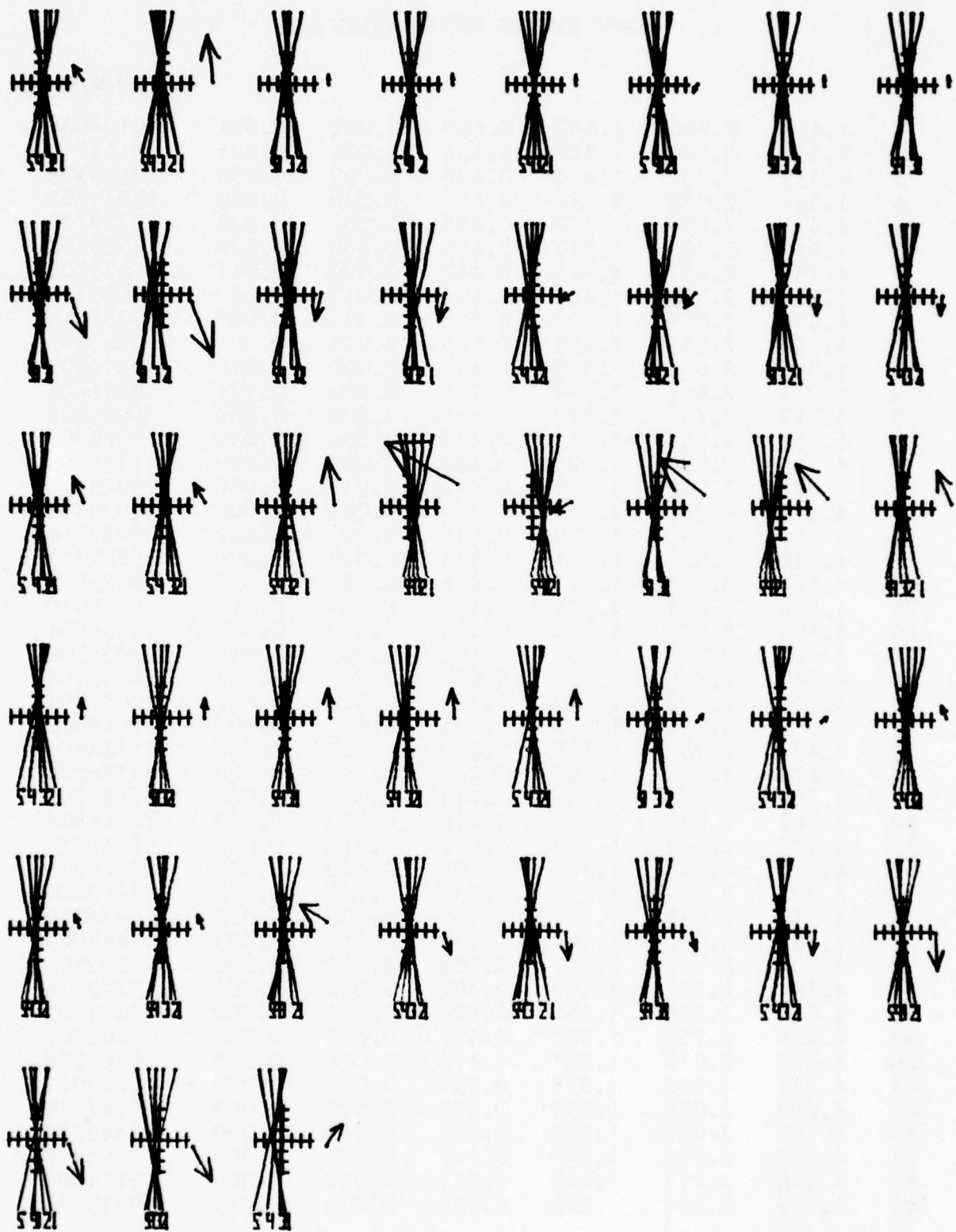
## SOURCE 3

## SOUND RANGING ARRIVAL TIMES &amp; MET

.1°C/10m/knots

1	1.388	0.471	0.009	0.000	0.468	1.388	10128804
2	1.373	0.457	0.000	0.025	0.527	1.473	8134710
3	1.394	0.480	0.003	0.000	0.481	1.392	13035902
4	1.377	0.473	0.000	0.011	0.468	1.380	13035902
5	1.373	0.463	0.000	0.000	0.460	1.369	13035902
6	1.364	0.460	0.000	0.011	0.470	1.392	13209302
7	1.379	0.474	0.000	0.002	0.475	1.376	15535702
8	1.379	0.484	0.017	0.000	0.467	1.371	15535702
9	1.464	0.534	0.040	0.000	0.441	1.321	5463609
10	1.411	0.489	0.004	0.000	0.482	1.393	9063313
11	1.401	0.492	0.012	0.000	0.474	1.391	8606606
12	1.394	0.468	0.005	0.000	0.463	1.358	8606606
13	1.338	0.449	0.000	0.023	0.520	1.471	8214603
14	1.353	0.444	0.000	0.027	0.503	1.423	8511204
15	1.387	0.467	0.000	0.012	0.499	1.415	8005304
16	1.392	0.479	0.000	0.002	0.470	1.399	8005304
17	1.344	0.449	0.000	0.002	0.476	1.421	11131306
18	1.396	0.479	0.008	0.000	0.477	1.408	9929405
19	1.368	0.451	0.000	0.009	0.487	1.409	12234310
20	1.184	0.365	0.000	0.096	0.654	1.654	8524521
21	1.405	0.483	0.009	0.000	0.449	1.350	7015905
22	1.218	0.389	0.000	0.067	0.620	1.608	6025914
23	1.199	0.373	0.000	0.090	0.640	1.634	5027311
24	1.329	0.432	0.000	0.037	0.550	1.500	8731208
25	1.421	0.489	0.011	0.000	0.472	1.405	9236604
26	1.370	0.467	0.001	0.000	0.469	1.371	9236604
27	1.371	0.469	0.007	0.000	0.466	1.377	8235106
28	1.351	0.454	0.000	0.012	0.509	1.450	8235106
29	1.389	0.474	0.005	0.000	0.467	1.401	8235106
30	1.404	0.492	0.005	0.000	0.485	1.394	11944602
31	1.396	0.486	0.006	0.000	0.468	1.388	11146502
32	1.383	0.480	0.009	0.000	0.453	1.351	12931203
33	1.329	0.448	0.000	0.015	0.497	1.416	12931203
34	1.393	0.481	0.004	0.000	0.473	1.384	12931203
35	1.313	0.434	0.000	0.059	0.577	1.536	6924808
36	1.459	0.520	0.020	0.000	0.449	1.349	6863805
37	1.429	0.484	0.000	0.007	0.487	1.411	6202706
38	1.404	0.487	0.016	0.000	0.467	1.376	5200604
39	1.427	0.499	0.009	0.000	0.463	1.393	7405305
40	1.401	0.478	0.000	0.005	0.469	1.382	6403508
41	1.463	0.514	0.017	0.000	0.435	1.342	6763809
42	1.431	0.506	0.019	0.000	0.449	1.333	5461809
43	1.387	0.482	0.015	0.000	0.469	1.404	9843706

# POLYGON OF ERROR PLOTS



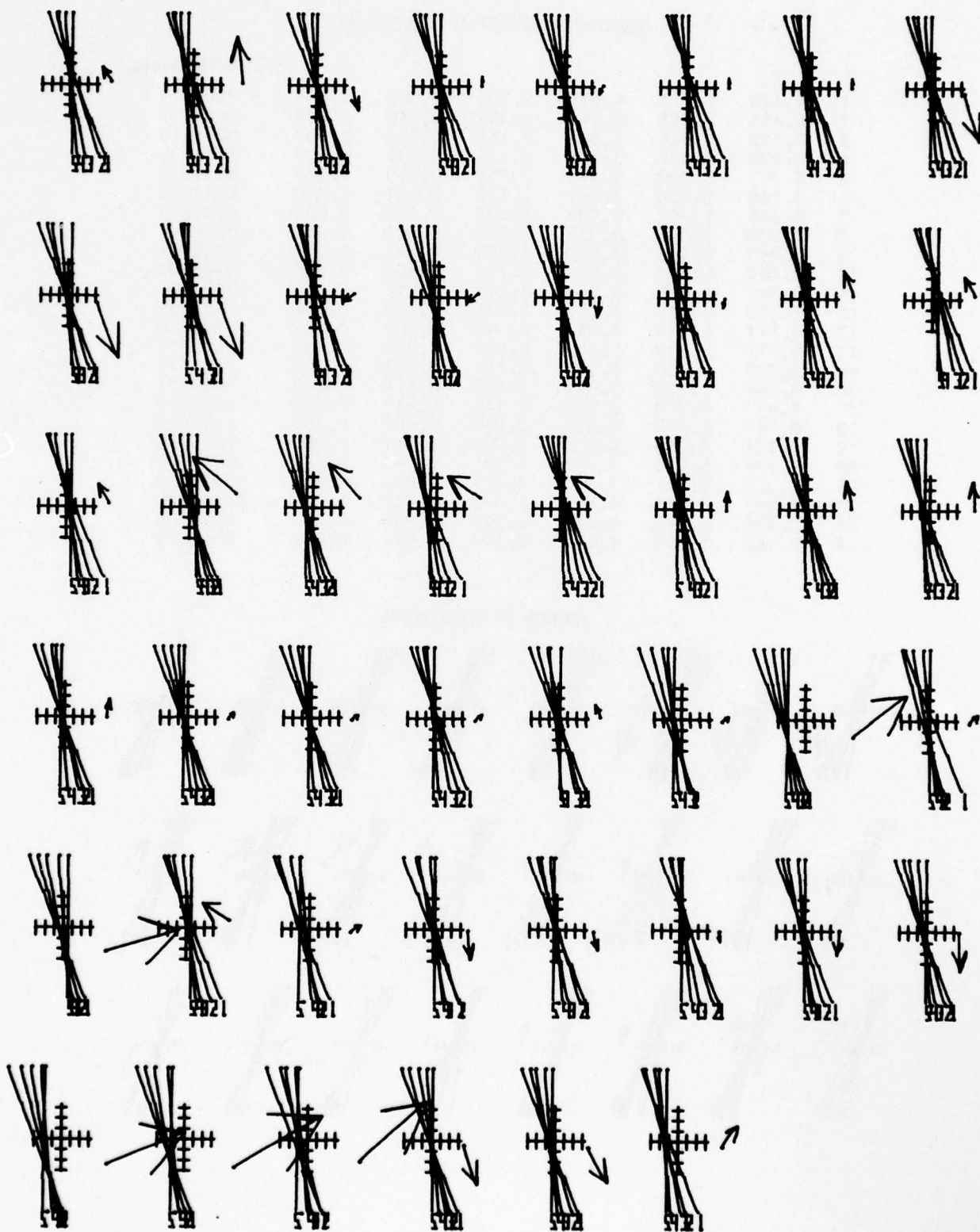
## SOURCE 4

## SOUND RANGING ARRIVAL TIMES &amp; MET

.1°C/10m/knots

1	4.406	2.700	1.362	0.456	0.000	0.004	10128804
2	4.361	2.654	1.326	0.434	0.000	0.026	8134710
3	4.455	2.752	1.410	0.489	0.009	0.000	12500505
4	4.387	2.689	1.366	0.463	0.000	0.000	13035902
5	4.375	2.691	1.370	0.465	0.006	0.000	13209302
6	4.410	2.704	1.373	0.463	0.000	0.000	15535702
7	4.355	2.667	1.345	0.442	0.000	0.011	15535702
8	4.526	2.789	1.429	0.496	0.013	0.000	7600111
9	4.606	2.869	1.501	0.557	0.056	0.000	9063313
10	4.590	2.852	1.489	0.523	0.022	0.000	9063313
11	4.385	2.683	1.349	0.445	0.000	0.010	8214603
12	4.273	2.611	1.312	0.433	0.000	0.034	8214603
13	4.393	2.702	1.372	0.463	0.000	0.005	8005304
14	4.332	2.640	1.319	0.432	0.000	0.030	9905802
15	4.313	2.626	1.323	0.440	0.000	0.028	11131306
16	4.456	2.739	1.399	0.472	0.010	0.000	9929405
17	4.412	2.702	1.377	0.471	0.002	0.000	9929405
18	4.190	2.550	1.279	0.416	0.000	0.042	6025914
19	4.148	2.507	1.241	0.391	0.000	0.078	5027311
20	4.122	2.474	1.217	0.381	0.000	0.077	6425010
21	4.316	2.631	1.321	0.432	0.000	0.042	6425010
22	4.409	2.700	1.373	0.465	0.000	0.023	9236604
23	4.402	2.709	1.385	0.469	0.000	0.017	8833506
24	4.343	2.650	1.330	0.438	0.000	0.021	8235106
25	4.409	2.709	1.382	0.462	0.000	0.012	10037804
26	4.385	2.695	1.373	0.463	0.000	0.007	11944602
27	4.433	2.730	1.396	0.470	0.003	0.000	11146502
28	4.474	2.753	1.407	0.476	0.006	0.000	11146502
29	4.361	2.678	1.362	0.449	0.002	0.000	12931203
30	4.307	2.647	1.345	0.445	0.000	0.020	12846602
31	4.479	2.768	1.429	0.502	0.018	0.000	12846517
32	4.472	2.747	1.425	0.505	0.020	0.000	12345503
33	4.981	3.182	1.752	0.732	0.140	0.000	11949820
34	4.315	2.628	1.323	0.441	0.000	0.022	6924808
35	4.388	2.694	1.383	0.471	0.000	0.023	11647003
36	4.500	2.785	1.427	0.502	0.012	0.000	6202706
37	4.494	2.767	1.409	0.482	0.000	0.002	5200604
38	4.567	2.826	1.450	0.506	0.011	0.000	8001102
39	4.426	2.715	1.383	0.474	0.004	0.000	7405305
40	4.423	2.716	1.381	0.470	0.004	0.000	6403508
41	4.711	2.962	1.575	0.597	0.058	0.000	12049022
42	4.828	3.053	1.650	0.658	0.090	0.000	13247726
43	4.798	3.029	1.613	0.621	0.067	0.000	11345922
44	4.562	2.831	1.475	0.527	0.027	0.000	6763809
45	4.546	2.811	1.449	0.513	0.022	0.000	5461809
46	4.369	2.664	1.348	0.444	0.000	0.019	9843706

# POLYGON OF ERROR PLOTS



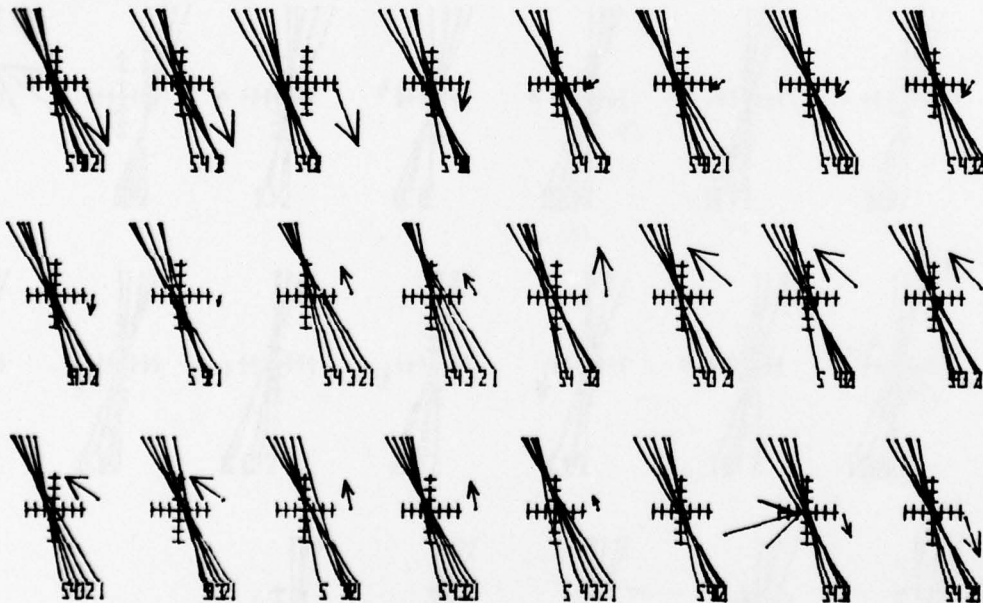
SOURCE 5

SOUND RANGING ARRIVAL TIMES & MET

.1°C/10m/knots

1	8.449	6.103	4.039	2.309	0.941	0.000	9063313
2	8.455	6.125	4.060	2.305	0.940	0.000	9063313
3	8.122	5.844	3.844	2.167	0.872	0.000	9063313
4	8.202	5.920	3.917	2.226	0.897	0.000	8606606
5	8.293	5.990	3.950	2.234	0.909	0.000	8214603
6	8.149	5.856	3.852	2.183	0.881	0.000	8214603
7	8.244	5.945	3.926	2.227	0.900	0.000	8511204
8	8.270	5.967	3.937	2.231	0.902	0.000	8511204
9	8.250	5.949	3.920	2.225	0.911	0.000	8005304
10	8.201	5.911	3.911	2.226	0.896	0.000	9905802
11	8.327	6.006	3.961	2.245	0.913	0.000	11131306
12	8.268	5.947	3.912	2.215	0.899	0.000	9929405
13	8.111	5.835	3.830	2.148	0.868	0.000	12234310
14	8.013	5.750	3.764	2.121	0.849	0.000	5526313
15	8.023	5.768	3.788	2.131	0.841	0.000	5526313
16	8.094	5.820	3.818	2.159	0.876	0.000	5027311
17	7.997	5.730	3.755	2.113	0.846	0.000	6425010
18	8.157	5.878	3.878	2.200	0.900	0.000	6425010
19	8.354	6.039	4.000	2.286	0.911	0.000	8833506
20	8.220	5.920	3.900	2.206	0.890	0.000	8833506
21	8.245	5.937	3.910	2.209	0.884	0.000	12931203
22	8.855	6.445	4.307	2.492	1.036	0.000	11949820
23	8.390	6.070	4.021	2.291	0.939	0.000	6863805
24	8.448	6.108	4.046	2.300	0.942	0.000	6763809

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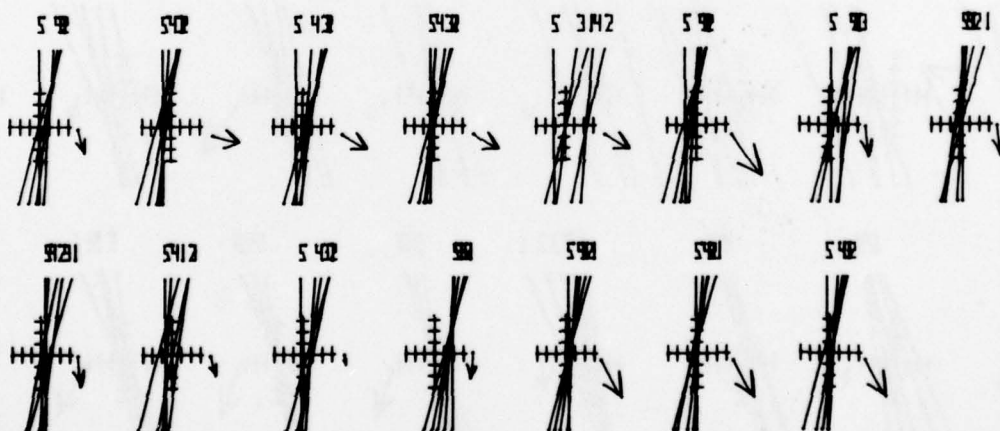


# SOURCE 6

## SOUND RANGING ARRIVAL TIMES & MET

							.1°C/10m/knots
1	3.334	2.057	1.063	0.375	0.008	0.000	15200205
2	3.365	2.079	1.075	0.380	0.020	0.000	11453907
3	3.471	2.155	1.125	0.404	0.021	0.000	12656407
4	3.420	2.116	1.099	0.396	0.030	0.000	12656407
5	3.524	2.211	1.143	0.439	0.008	0.000	12656407
6	3.360	2.076	1.074	0.384	0.014	0.000	15060411
7	3.423	2.121	1.114	0.392	0.010	0.000	6202706
8	3.305	2.009	1.023	0.360	0.012	0.000	6202706
9	3.380	2.068	1.073	0.370	0.018	0.000	6202706
10	3.299	2.031	1.031	0.335	0.000	0.009	5200604
11	3.356	2.060	1.049	0.359	0.000	0.003	8001102
12	3.431	2.128	1.115	0.417	0.045	0.000	7405305
13	3.501	2.172	1.141	0.427	0.039	0.000	5461809
14	3.431	2.116	1.105	0.402	0.029	0.000	5461809
15	3.454	2.145	1.118	0.407	0.026	0.000	5461809

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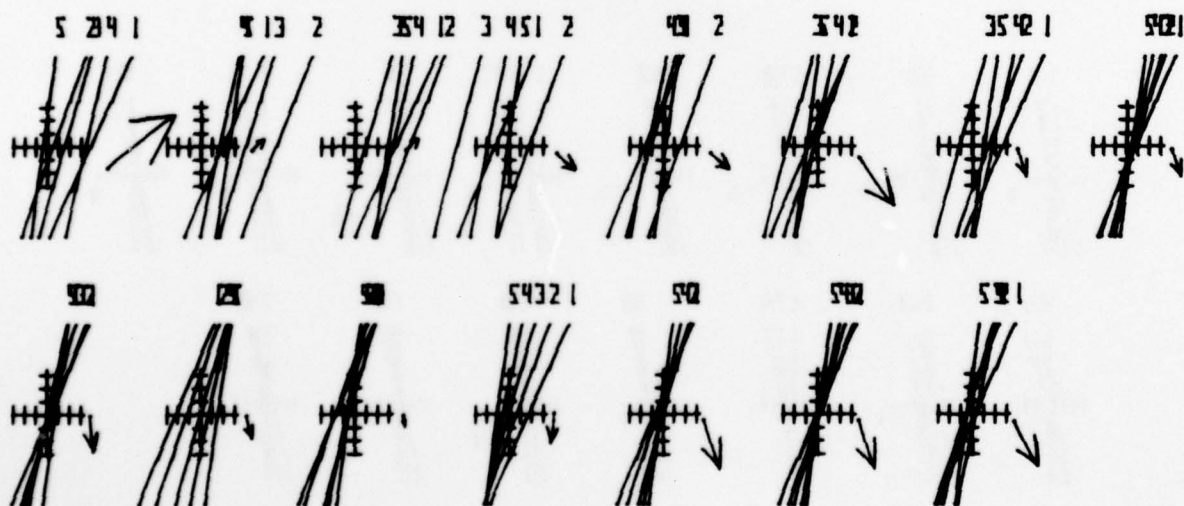


# SOURCE 7

## SOUND RANGING ARRIVAL TIMES & MET

							.1°C/10m/knots
1	6.863	4.914	3.271	1.880	0.741	0.000	12846517
2	6.667	4.821	3.134	1.764	0.736	0.000	12345503
3	6.646	4.772	3.119	1.812	0.746	0.000	12345503
4	6.273	4.466	2.854	1.650	0.688	0.000	10258305
5	6.357	4.557	2.950	1.671	0.696	0.000	10258305
6	6.351	4.531	2.950	1.693	0.682	0.000	15060411
7	6.501	4.626	3.023	1.743	0.707	0.000	6863805
8	6.449	4.606	3.021	1.707	0.694	0.000	6863805
9	6.395	4.568	2.988	1.690	0.694	0.000	6202706
10	6.372	4.582	3.030	1.732	0.717	0.000	5200604
11	6.220	4.435	2.906	1.630	0.658	0.000	8001102
12	6.300	4.460	2.890	1.610	0.640	0.000	7405305
13	6.405	4.580	3.003	1.694	0.687	0.000	6763809
14	6.450	4.612	3.021	1.709	0.694	0.000	6763809
15	6.483	4.625	3.036	1.723	0.693	0.000	5461809

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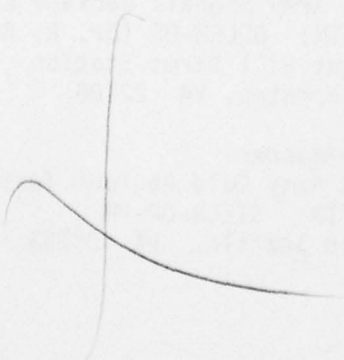
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